Technical Investigation of the May 22, 2011, Tornado in Joplin, MO

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SDR Briefing

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Joplin Tornado Overview

- Touched down at 5:34 PM CDT, Sunday, May 22, 2011.[1] Stayed on ground for about 22 miles (6 miles in City of Joplin) and 15 minutes
- Enhanced Fujita Scale EF-5 tornado[1] (highest category)
- Estimated maximum wind speeds: 200+ mph
- Damaged/destroyed ~ 8,000 buildings.[2] Affected ~41% of City's population (20,820 of 50,175[3]). Costliest tornado on record (~$1.8 billion insured loss[2])
- 161 fatalities, >1,000 injuries. Deadliest single tornado on record.
  Exceeds U.S. average deaths/year for all tornados (91.6) [1], hurricanes(50.8) [1], & earthquakes (7.5) [4]
- Official warning time of 17 minutes (national average is 14 minutes[1])

Sources: [1]National Weather Service, [2]City of Joplin, [3]U.S. Census Bureau, 2010 Census, [4]U.S. Geological Survey

National Construction Safety Team

Following a preliminary reconnaissance that began on May 24, 2011, the NIST Director established a Team under the NCST Act on June 29, 2011, to conduct a technical investigation of the Joplin Tornado.

- Team Members
  - NIST Engineering Laboratory employees
    - Dr. Marc Levitan: Investigation Team Leader, Wind Engineer, Leader of NIST NWIRP R&D
    - Dr. Erica Kuligowski: Fire Protection Engineer and Sociologist
    - Dr. Frank Lombardo: Wind Engineer and Meteorologist
    - Dr. Long Phan: P.E., Structural Engineer
  - National Oceanic and Atmospheric Administration (NOAA) employee
    - Dr. David Jorgensen: Research Meteorologist and Chief, National Severe Storms Lab (NSSL)/Warning R&D Div.

Goals

- To investigate the wind environment and technical conditions associated with fatalities and injuries, the performance of emergency communications systems and the public response to such communications, and the performance of residential, commercial, and critical buildings, designated safe areas in buildings, and lifelines
- To develop findings and recommendations that can serve as the basis for:
  - Potential improvements to requirements for design and construction of buildings
  - designated safe areas, and lifeline facilities in tornado–prone regions
  - Potential improvements to guidance for tornado warning systems and emergency response procedures
  - Potential revisions to building, fire, and emergency communications codes, standards, and practices
  - Potential improvements to public safety

Objectives

1. Determine the tornado hazard characteristics and associated wind fields in the context of historical data
2. Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas
3. Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings
4. Determine the pattern, location, and cause of fatalities and injuries, and associated emergency communications and public response
5. Identify, as specifically as possible, areas in current building, fire, and emergency communications codes, standards, and practices that warrant revision

Near-Surface Wind Environment

- Indirect Method: EF-scale
  - Rated NIST-surveyed structures using EF-scale and compared with ratings of others
  - Variability in ratings increase with large structures

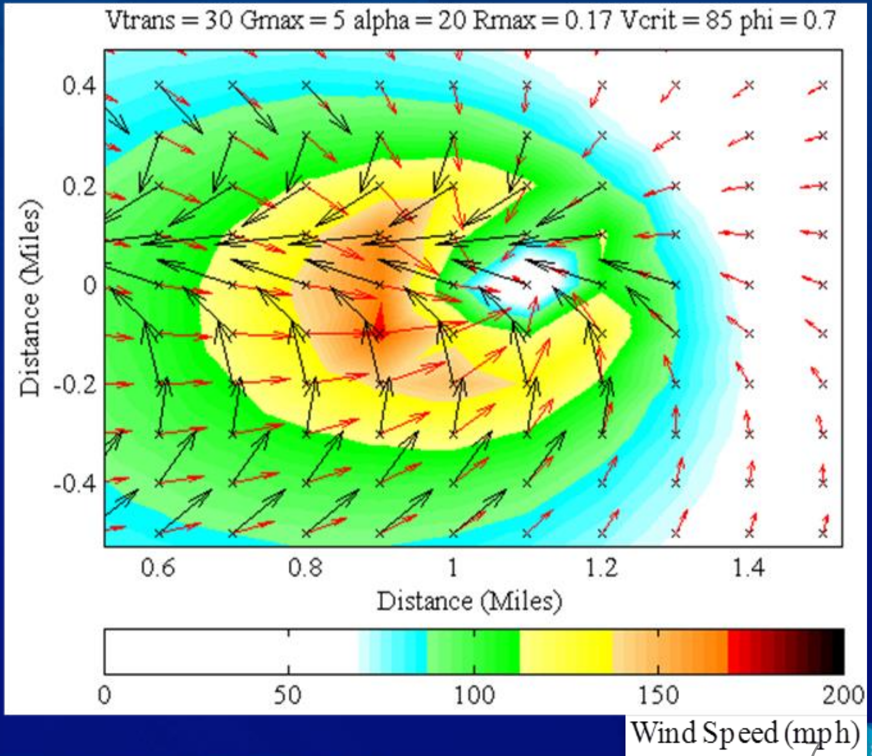
Table 2–2. Estimated wind speeds for NIST-surveyed structures using EF Scale.

NIST-Surveyed Structure	Damage Indicator (DI)*		Degree of Damage (DOD)**		Estimated Wind Speed (mph)		Estimated EF Number	
	NIST	Other	NIST	Other	NIST	Other	NIST	Other
Walmart	12	12[a,d]	6–7	6[a], 7[d]	140 ± 15	173[d]	3	4[a,d]
Home Depot	12	12[a]	6–7	7[a]	150 ± 15	N/A	3	4[a]
Franklin Technology Center	15	15[d]	9	9[d]	150 ± 15	153[d], 143[e]	3	3[d,e]
SJRMC (East/West Towers)	20	20[a,c]	7	10[a,c]	140 ± 15	148[c]	3	3[a,c]
Joplin East Middle School	16	16[d]	8–9	7[d]	140 ± 15	125[d], (137–164)[b]	3	2[a,d], 3[b]
Joplin High School	16	16[a,d]	8–9	11[a], 9[d]	140 ± 15	120[b], 139[d], 158[e]	3	2[b], 3[a,d,e]

*DI numbers: 12, large, isolated retail building; 15, elementary school (the Franklin Technology Center was not an elementary school but was a building of similar construction); 16, junior or senior high school; 20, institutional building.
**DOD numbers: see Texas Tech University 2006 (Available online at http://www.depts.ttu.edu/nwi/Pubs/FScale/EFScale.pdf).
a. FEMA 2012.
b. Miller and Coulbourne 2012. (Estimated wind speed values back-calculated)
c. Prevatt et al. 2012.
d. Marshall 2012.
e. Karstens et al. 2012.
Key: SJRMC, St. John's Regional Medical Center.

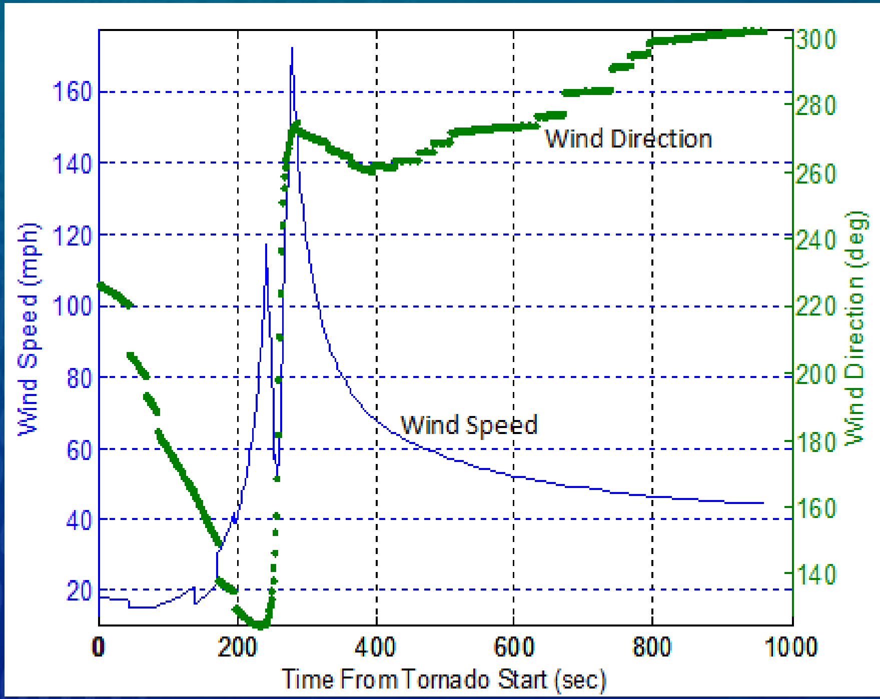
Near-Surface Wind Environment

- Indirect Method: Tornado Wind Field Model (Rankine vortex)
  - Thousands of trees felled in Joplin
  - Initialize tornado wind field model in simulations to “re-create” observed tree fall
  - Grid system was created throughout Joplin and wind field model translated through it (250 ft or 80 m spacing)



Near-Surface Wind Environment

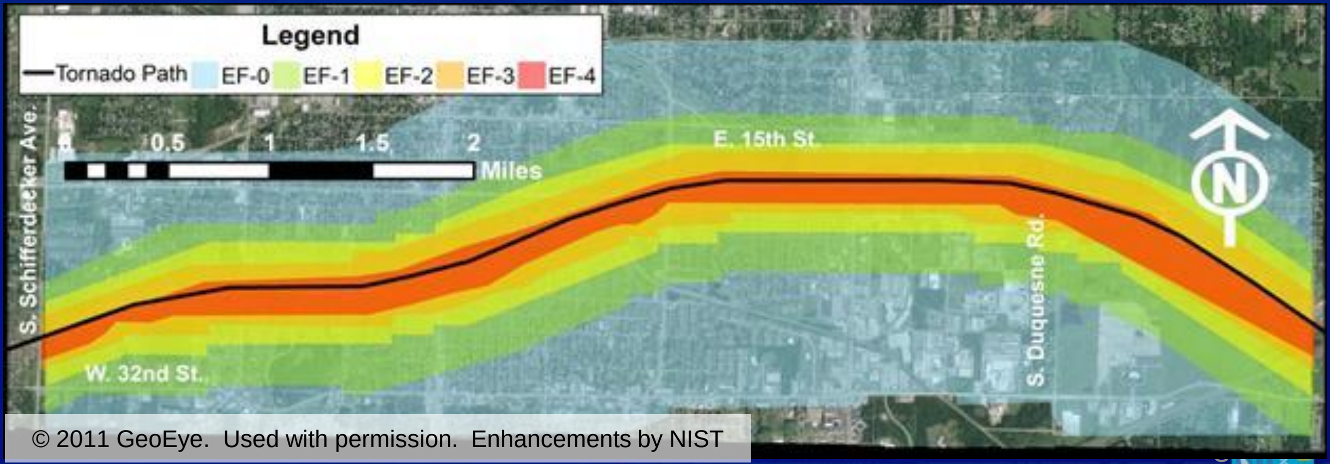
- Grid-based simulation – time histories and spatial estimations



Estimated wind speed and direction time history for a specific grid-point

Estimated maximum wind speed associated with EF-number in Joplin

EF Number	Wind Speed (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	200+



Selected Findings: Tornado Hazard Characteristics

- F1: Current NWS radar technology is incapable of determining tornado occurrence and intensity at heights above ground that are relevant to structural engineering design. Closest radar to Joplin was 60 miles (100 km) away.
- F3: NIST estimated the maximum wind speeds in the Joplin tornado to be 175 mph with an upper bound of 210 mph. Existing indirect methods have considerable uncertainty in estimating wind speeds for structural design.
- F7: The Enhanced Fujita scale lacks adequate damage indicators (DIs) and corresponding degrees of damage (DODs) for distinguishing among the most intense tornado events. The lack of DIs and DODs and overall nature of the EF-scale results in subjective, non-quantitative assessment of tornado damage.

Summary of Building-Related Damage, Fatalities, and Insured Losses

Buildings Damaged	Residential	**7,411 (43% sustained *heavy/totaled or demolished classification)***
	Non–Residential	**553 (1 of 2 major hospitals, 10 public and several parochial schools, 28 churches, 2 fire stations, and numerous commercial facilities)**
Fatalities	Total	**161**
	All Building–Related	**135 (of 161, or 83.8% of total fatalities)**
	Residential-Related	**74 (of 135, or 52.5% of building–related fatalities)**
Insured Losses **(as of April 30, 2012)**	Residential	**$0.552 billion**
	Commercial	**$1.228 billion**

Building Performance Findings – Context

- National model building codes, standards, and practices seek to achieve life safety for the hazards considered in design. Tornado hazards are not considered in the design of buildings currently, except for safety–related structures in nuclear power plants, storm shelters, and safe rooms.
- Like most other municipalities in tornado–prone areas and the contemporaneous model building codes, the City of Joplin did not mandate the construction of shelters or safe rooms in residential or non–residential facilities.

  Additionally, the City did not own or operate any public storm shelters.

  The lack of public shelters and requirements for safe rooms meant that many residents, particularly those who were living in multi–family residential buildings or older nursing homes, did not have access to such sheltering options during this tornado.

Selected Findings: Building Performance

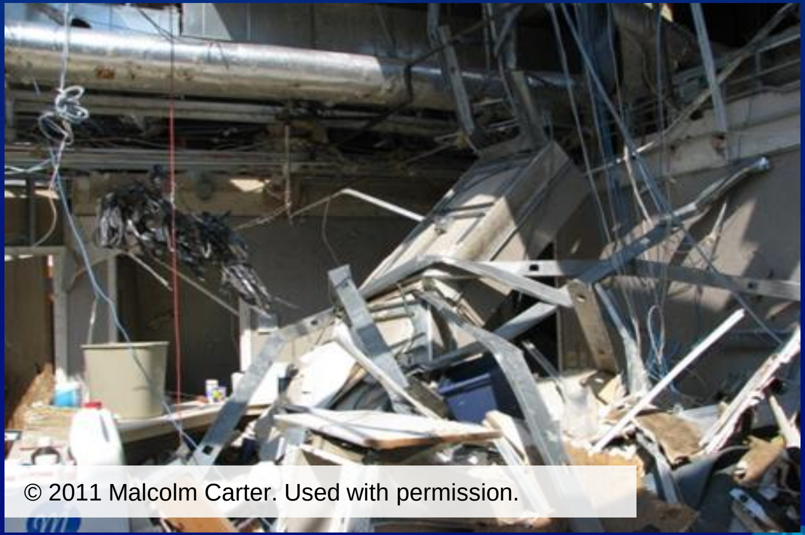
- F8: Buildings are not designed to withstand tornado hazards (extreme wind speeds and wind-borne debris). Most buildings in the damaged area of Joplin were subjected to wind speeds close to or above the non-tornadic wind design requirements of applicable building codes.
- F9: Regardless of construction type, buildings were not able to provide life–safety protection. Of the 161 fatalities, 135, or 83.8 percent, were related to building failure (slightly more than half in residential buildings, the rest in non-residential buildings).

Selected Findings: Building Performance

- F10: Engineered buildings that:
  - Had redundant lateral load capacity or that did not depend on roof bracing (steel and concrete moment frames) withstood the tornado without collapse.
  - Had reinforced concrete or composite concrete-steel roof also withstood the tornado without collapse.
  - Relied on bracing from a less robust roof system (such as box–type system (BTS) buildings with light steel roof decks) were prone to structural collapse.

Selected Findings: Building Performance

- F16: All NIST–surveyed engineered buildings that did not collapse, as well as engineered buildings that collapsed, sustained significant damage to the envelopes and interiors due to the combination of wind pressure, impacts by wind–borne debris, and water intrusion.
- F17: The failure of building envelopes at SJRMC, which led to loss of protection and subsequent extensive damage to building interiors, was the primary cause for the complete loss of functionality of this critical facility despite the robust structural system that withstood the tornado without structural collapse.



Selected Findings: Shelters/SafeRooms/ Designated Refuge Areas

- F20: Joplin residents had limited access to underground or tornado–resistant shelters. There were no community shelters or safe rooms in the City of Joplin or Jasper County at the time. About 82 percent of the homes in Joplin did not have basements. Only a few non–residential buildings had underground locations (e.g., basements).

- F21: Most high–occupancy commercial and critical facilities surveyed by NIST had designated refuge areas for tornadoes. However, many of these areas suffered severe damage and yielded no positive outcomes with respect to loss of life. The locations of these areas were not always based solely on structural considerations.

  There are currently no standards, requirements, or guidelines for designating refuge areas in commercial or critical buildings

Data Collected on Public Response and Emergency Communications

- 168 survivors (telephone/face-to-face interviews)
- Over 100 media accounts of stories of survival
- Targeted interviews with and data collection from emergency response personnel (inside and outside City of Joplin, MO)
- Death certificates obtained for all deaths
- Additional sources on deaths :

  NWS; MO State Police; Dr. Andrew Curtis; media accounts; NIST survivor interviews; social media; obituaries; American Red Cross

- Information on injuries obtained from:
  - MO Department of Health and Senior Services
  - CDC EPI-Aid Study (Source: MO Department of Health and Senior Services)

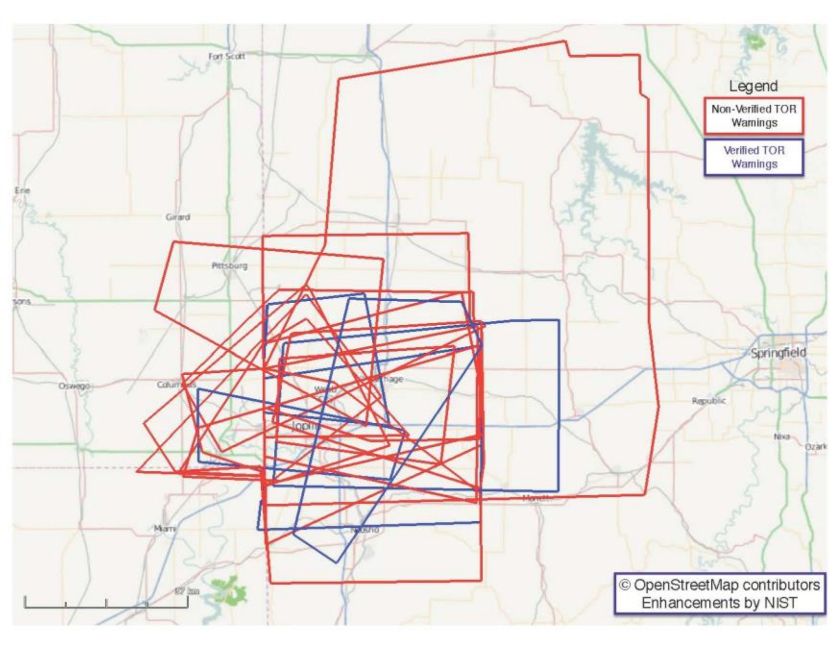
Selected Findings: Fatalities

- F28: The Missouri State Police attributed 161 deaths and the City of Joplin attributed more than 1,000 injuries to the Joplin tornado, which affected an area with an estimated population of 20,820.

- F29: Of the 161 deaths resulting from this tornado:
  - 155 (96 percent) were caused by impact–related factors (i.e., multiple blunt force trauma to the body).
  - Others were caused by stress–induced heart attacks, pneumonia, or lightning.

Selected Findings: Emergency Communications

- F30/31: False alarm rates:
  - There was evidence of high false–alarm rates among the storm–based tornado warnings officially issued for Joplin.
  - Despite public perception, no evidence was found of high false–alarm rates for Joplin’s outdoor siren system.



- F32: Joplin residents interviewed after the Joplin tornado believed that there had been a high number of false alarms in Joplin from official tornado warnings <u>and</u> the City’s outdoor siren system prior to 2011, even though the siren activation rate was once per year (on average).

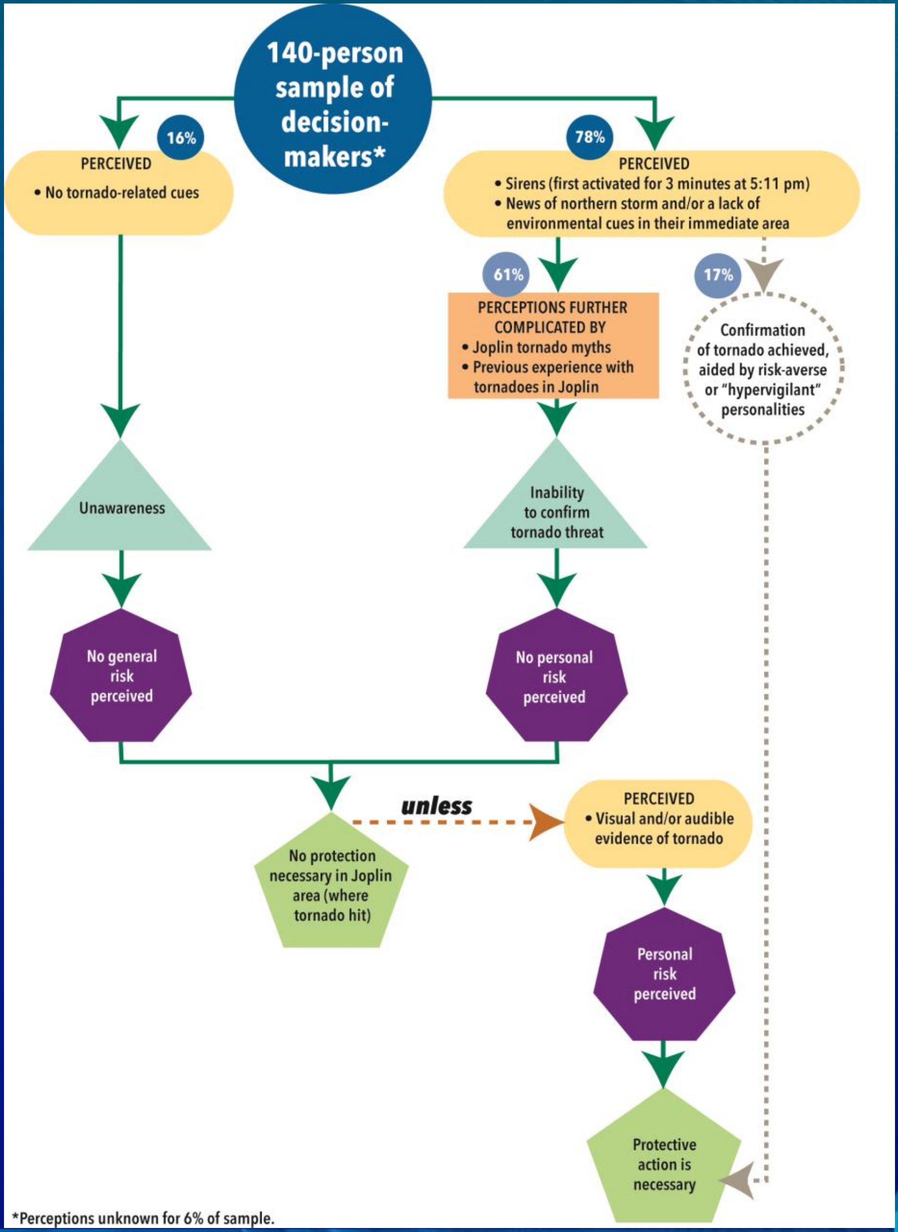
Selected Findings: Emergency Communications

- F38: Functioning as an alerting system, only, the outdoor sirens prompted many Joplin residents and visitors to seek further information on May 22, 2011. The multiplicity of information sources, and the conflicting information provided by those sources, added to the public's confusion about the true hazard as additional information was sought.

- F39: Across the country, there is no standard method for sounding outdoor public siren systems, which has led to variations in siren usage, activation procedures, and sounding patterns among U.S. communities. Also, there are no nationally accepted standard protocols for the issuance of an all–clear alert following a warning.

Selected Findings: Public Response

- F43: Responses to the approaching tornado among members of the public, in many cases, were delayed or incomplete
- F44: Two factors were found to have contributed:
  - Lack of awareness
  - Inability to perceive personal risk



Selected Findings: Public Response

- F45: The main factor that convinced individuals to take shelter was the receipt of high–intensity cues, including hearing or seeing the tornado approaching or witnessing others' urgency related to taking protection.

- F46: No fatalities occurred in demolished, detached homes in which people took refuge in basements. Additionally, NIST found no evidence that any of those killed were located underground during the tornado.

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 1: Tornado Hazard Characteristics and Associated Wind Field		
R1: NIST recommends that a capacity be developed and deployed that can measure and characterize actual near–surface tornadic wind fields for use in the engineering design of buildings and infrastructure. This would require enhancement and widespread deployment of advanced technologies, including weather radar.	Academia, Industry, NOAA/NWS, NRC,NSF,DOE	NOAA
R2: NIST recommends that information gathered and generated from tornado events (such as the Joplin tornado) should be stored in publicly available and easily accessible databases to aid in the improvement of tornado hazard characterization.	Academia, FEMA, Industry, NGA, NOAA/NWS	NOAA

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 1: Tornado Hazard Characteristics and Associated Wind Field		
R3: NIST recommends that tornado hazard maps for use in the engineering design of buildings and infrastructure be developed considering spatially based estimates of the tornado hazard instead of point–based estimates.	ASCE, DOE, FEMA, ICC, NRC	NIST
R4: NIST recommends that new damage indicators (DIs) be developed for the Enhanced Fujita tornado intensity scale to better distinguish between the most intense tornado events. Methodologies used in the development of new DIs and associated degrees of damage (DODs) should be, to the extent possible, scientific in nature and quantifiable. As new infor-mation becomes available, a committee comprised of public and private entities should be formed with the ability to propose, accept, and implement changes to the EF Scale. The improved EF Scale should be adopted by NWS.	Academia, FEMA, Industry, NOAA, NSF, Office of Science and Technolog y Policy	NOAA/NWS

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 2: Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines		
R5: NIST recommends that nationally accepted performance–based standards for tornado–resistant design for buildings and infrastructure be developed in model codes and adopted in local regulations to ensure the resiliency of communities to tornado hazards. The standards should encompass tornado hazard characterization, performance objectives, and evaluation tools. The standards shall require that critical buildings and infrastructure such as hospitals and emergency operations centers are designed so as to remain operational in the event of a tornado.	Academia, ASCE, Design and construction industry (ACI, AISC, AWS, PCA, SDI, SJI, TMS), FEMA, ICC, NIST	ASCE

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 2: Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines		
R6: NIST recommends the development of risk–consistent, performance–based tornado design methodologies to ensure that all building components and systems meet the same performance objectives when subjected to tornado hazards.	Academia, ASCE, Design and construction industry, ICC.	NIST, FEMA
R7: NIST recommends that (a) model building codes for new buildings require that tornado shelters be designed in accordance with the ICC 500 standard, (b) model building codes develop and adopt a tornado shelter standard specific for existing buildings, and (c) tornado shelters be installed in new and existing multi–family residential buildings, mercantile buildings, and buildings with assembly occupancies located in tornado hazard areas identified in the performance–based standards required by Recommendation 5.	Academia, FEMA, ICC, States and AHJs in tornado–prone areas	ICC

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 2: Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines		
R8: NIST recommends the development and implementation of uniform national guidelines that enable communities to create the safest and most effective public sheltering strategies. The guide-lines should address planning for, siting, designing, installing, and operating public tornado shelters within the community.	FEMA, ICC, NFPA, NWS, NSF	FEMA
R9: NIST recommends that uniform guidelines be developed and implemented nationwide for con-ducting tornado risk assessments and designating best available tornado refuge areas as an interim measure within buildings until permanent measures fully consistent with Recommendations 5 and 7 are implemented.	Academia, FEMA, DHS S&T, ICC, States and AHJs in tornado–prone areas	FEMA
R10: NIST recommends that aggregate, gravel, or stone be prohibited as roof surfacing material or roof ballast for buildings of any height in tornado–prone areas.	ASCE, ICC, States and AHJs	ICC

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 2: Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines		
R11: NIST recommends that enclosures for egress systems (elevators, exits) of critical facilities in tornado–prone areas be designed to maintain their functional integrity when subjected to tornado hazards.	Building owners/operators, ICC	ICC
R12: NIST recommends that owners and operators of existing critical facilities in tornado–prone areas perform tornado vulnerability assessments and take steps to ensure the functionality of (1) backup power supplies (harden the protection of emergency backup power, as region–wide losses of power due to damage to power transmission infrastructure occur frequently in tornadoes), (2) vertical movement within the building (elevator equipment and shaft enclosures), and (3) means of egress illumination (battery–powered lighting in addition to backup power), in a tornado event.	DHS S&T, Building owners/operators, States and AHJs	DHS IP/FEMA

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 3: Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response		
R13: NIST recommends the development of national codes and standards and uniform guidance for clear, consistent, and accurate emergency communications, encompassing alerts and warnings, to ensure safe, effective, and timely responses among individuals, organizations, and communities in the path of storms having the potential to create tornadoes. NIST also recommends that emergency managers, the NWS, and the media develop a joint plan and take steps to ensure that accurate and consistent emergency alert and warning information is communicated in a timely manner to enhance the situational awareness of community residents, visitors, and emergency responders affected by an event.	Academia, ICC, NEMA, NFPA, NWS, DHS/FEMA	ICC, NFPA

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 3: Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response		
R14: NIST recommends that the full range of current and next–generation emergency communication "push" technologies (e.g., GPS–based mobile alerts and warnings, reverse 9–1–1, outdoor siren systems with voice communication, NOAA weather radios) be widely deployed and utilized, to maximize each individual's opportunity to receive emergency information and respond safely, effectively, and in a timely fashion.	Academia, DHS/FEMA, FCC, NOAA/NWS	NOAA

Recommendations	Interested Parties	Organization with Lead Responsibility for Implementation
Group 3: Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response		
R15: NIST recommends research studies to identify the factors that will significantly enhance public perception of personal risk and how such knowledge can be better used to rapidly and effectively respond during tornadic events.	Academia, DHS, ICC, NFPA, NOAA/NWS	NSF, NIST
R16: NIST recommends that tornado threat information be provided to emergency managers, policy officials, and the media on a spatially resolved real–time basis by frequently updating gridded probabilistic hazard information that is merged with other GIS information to supplement the currently deployed binary warn/no warn system.	NOAA	NOAA

Investigation and Report Timeline to Completion

- Nov. 21, 2013 - draft for public comment released
- Jan. 6, 2014 – public comments due
- Spring 2014 – address public comments and publish final report
- Spring 2014 – complete and publish the Joplin Tornado Data Repository
- Spring 2014 – begin effort to implement recommendations

More information and draft report available at

- http://www.nist.gov/el/disasterstudies